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The additive technology to obtain a three-dimensional model of the 81Cu-19Ni alloy

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Abstract. This paper is devoted to the selective laser smelting (SLS) method description for the article made of powder of a Cu81-Ni19 copper-nickel alloy and the study of the structure and characteristics of the three-dimensional article made using additive technology. To make a 3D model the copper-nickel alloy powder was produced in our laboratory. The chemical composition, microstructure, density, surface roughness and microhardness of an article made of powders of a Cu81-Ni19 copper-nickel alloy are considered. A comparative analysis of the structure, physical and mechanical properties of a sample obtained by the SLS method and the annealed rolled plate was carried out. The article microstructure is characterized by the absence of a typical signs of a crystalline structure and contains elements of a quasi-amorphous state. At the same time, the obtained material differs from the standard monolith billet with a lower surface roughness and a higher hardness values while maintaining almost the same density indices.

1. Introduction
At present, additive technologies are one of the promising methods for producing finished products with the required properties [1]. They are based on the effect of concentrated energy flows on powder layers deposited in accordance with the spatial-geometric configurations of the formed article. As a result, the product is created in layers, by depositing the material under the action of a laser beam, which draws the shape of each layer until the object is completely ready. This technology is practically implemented for a wide list of various products, ranging from plastics to metal materials [2–4]. Among the metals, non-ferrous metals and their alloys can be noted [5, 6]. At the same time, there is no information regarding the use of selective laser smelting (SLS) technology as applied to Cu-Ni system alloys, the use of which for industrial needs, as well as for obtaining decorative products, is an urgent task. In this work, the aim of the study was to use the SLS method to obtain a three-dimensional article made of a copper-nickel alloy powder of the Cu81-Ni19 composition.

2. Material and study methods
A Cu81-Ni19 alloy was used as the material of substrate for selective laser smelting and wire billet for the powder manufacturing. The chemical composition of the industrial alloy Cu81-Ni19 was (mass %): 19.060 Ni, 0.157 Fe; 0.245 Si; the base alloy is Cu.

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To prepare the powder by flame spraying, a wire billet with a diameter of 0.8 mm was used. After thoroughly drying the powder fractions in the laboratory using an LPzE-2e shaker, the powder with a particle diameter of not more than 40 μm was screened. The manufacture of a three-dimensional sample was carried out using a 3D printing method on an industrial EOS M280 installation (laser power 200 W, laser spot diameter 100 μm, application of powder monolayers with a thickness of 20 μm). As a result, a three-dimensional sample was obtained in the form of a rectangular parallelepiped 30–30–10 mm in size (Figure 1). Sample has a simple form because our aim is to study the possibility of obtaining a dense sample made of copper-nickel alloy powder and a comparison of physical and mechanical properties. The three-dimensional sample was formed on the annealed plate basis that thickness was 4 mm. Therefore, we can compare the structure and properties of the three sections: 3D model, intermediate zone and monolith (Figure 2).

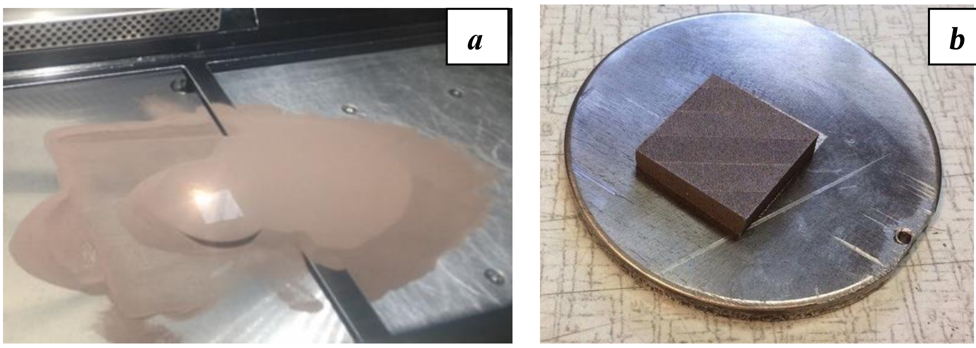

Figure 1. Obtaining a product from a copper-nickel alloy at the industrial EOS M280 installation: a – a three-dimensional sample forming step; b – finished sample.

The density ρ_0 was measured using a precision METTLER TO-LEDO balance. As the substance, distilled water and air were used. Microhardness tests were carried out by the standard method on a PMT-3 instrument with a load of 50 g (0.5 N). The surface topography study was carried out on an optical profile meter Optical Profiling System Veeco WYKO NT1100. For metallographic studies of the structure, an Epiquant automated microscope was used, as well as a ZEISS CrossBeam AURIGA scanning electron microscope. A hydrochloric acid solution of ferric chloride was used as an etchant.

3. Experimental data and discussion

For metallographic research samples microsections were prepared from both the annealed plate basis (arbitrarily designated as a monolith) and the three-dimensional sample after laser fusion (3D model).

A microstructure metallographic study of these samples (Figure 2) showed a fundamental difference in their structure. This is especially evident when using a more detailed view of the microstructure (see inserts). So, in the initial state (monolith), this alloy has a typical microstructure of annealed material with a face-centered cubic lattice. The existence of equiaxed grains (approximately 50 μm in size) with the presence of numerous wide annealing twins is observed. The sample structure subjected to the SLS method seems to be significantly different. It consists of many dispersed fragments, which have a characteristic form so-called turbulent vortex, preserving a drop-like configuration [7]. These structural fragments size is in the range of 70–100 μm.

A metallographic analysis of the three-dimensional sample obtained by laser smelting does not allow us to detect the characteristic features of a material that has undergone crystallization, there are no dendritic formations, and there are no signs that these structural objects have a grain structure with boundaries.

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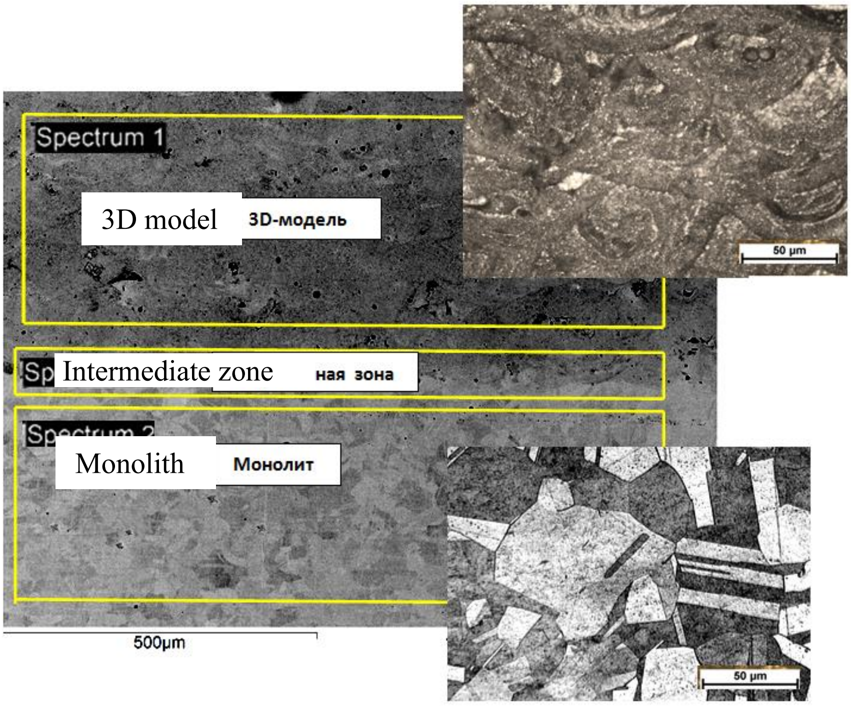

Figure 2. The Cu81-Ni19 alloy microstructure in the annealed state (monolith) and after laser smelting (3D model).

Table 1 shows the quantitative chemical analysis results of both specimens cut from the three-dimensional sample (position 1) and the monolith (position 2). The quantitative chemical analysis is obtained by energy dispersive spectrometry. As can be seen, the chemical composition is fully corresponding to the chemical composition for both technological states. A similar composition is recorded for the intermediate zone (position 3).

Table 1. The Cu81-Ni19 alloy chemical analysis (mass %) after various technological treatments.

Parameter	Ni	Cu	Total
Spectrum 1	20.01	79.99	100.00
Spectrum 2	19.10	80.90	100.00
Spectrum 3	19.60	80.40	100.00
Mean	19.57	80.43	100.00
Std. deviations	0.46	0.46	
Max	20.01	80.90	
Min	19.01	79.99	

The physical and mechanical characteristics such as density Ra, roughness Ra and microhardness HV0.5 were determined. The characteristics result of this alloy after various technological treatments are given in Table 2.

Density is an important indicator for assessing the physical property especially for a material smelted from powder fractions. As a result, the following data was obtained: the monolith density was 8.925 g/cm^3, and the smelted sample was 8.562 g/cm^3, i.e. the 3D model was formally less dense. However, this difference is not fundamental - it is only 4 %. Thus, we can conclude the selective laser smelting method under consideration allows to obtain a material that is almost identical in density to standard technology. Moreover, the measured density indices are actually similar to the values of pure copper (8.890 g/cm^3) [8].

Table 2. The Cu81-Ni19 alloy physic mechanical properties for the annealed state (monolith) and after laser smelting (3D model).

Sample	Physic mechanical properties		
	Density ρ, g/cm^3	Roughness R_a, nm	Microhardness $HV_{0.5}$
Monolith	8.925±0.005	710±15	62±3
3D model	8.562±0.005	660±20	75±3

The roughness parameters (relief profile) for the sample's surfaces obtained by various technologies have a certain difference: the sample obtained by laser smelted is characterized by relatively better 'smoothness'. A study of strength properties shows that the Cu81-Ni19 alloy microhardness is in the initial state, i.e. after annealing, was 62 HV. At the same time, the 3D model microhardness was 19 % higher and amounted to 75 HV.

The presented data concerning the structural study of the 3D model made of Cu81-Ni19 alloy and obtained by the SLS method give grounds to state the following consideration.

Under conditions when a local laser beam heats a thin powder layer, subsequent cooling in the molten areas proceeds at such a speed that it becomes possible to significantly suppress the crystallization process and fix the strongly supercooled liquid phase, i.e. obtaining an amorphous state (metal glass). Thus, after laser smelting, the finished 3D model is largely characterized by the presence of a quasi-amorphous state. This version is indirectly supported by the measurement of physical and mechanical properties. It was shown [9] that laser-smelted material is characterized by higher hardness and, in fact, may not be inferior in density terms. It is these characteristics that distinguish the 3D model made of the investigated alloy.

4. Summary

Using the selective laser smelted method a three-dimensional model made of the Cu81-Ni19 copper-nickel alloy is obtained. Structural studies have shown that the finished 3D model is not characterized by typical signs of a crystalline structure. It has been suggested that, under these conditions, the smelting process apparently led to the realization of a structural state close to amorphous.

It was shown that the smelted 3D model practically does not differ in density from the monolithic annealed analogue, but is significantly distinguished by a lower surface roughness, as well as higher hardness values.

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